Modified Geometry of Transition Slabs for Integral Bridges

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Abstract. Over the past decades, an increasing number of integral bridges have been built. This type of bridge offers various advantages in comparison with standard bridges equipped with expansion joints and bearings. In particular, integral bridges require less maintenance since they require less mechanical elements. Transition slabs, which are used in integral bridges, are directly connected to the bridge deck and therefore they are subjected to large displacements caused by creep, shrinkage and temperature effects. Consequently, detailing of transition slabs needs to be examined. This paper investigates new design approaches for transition slabs focusing on the road pavement settlement at the end of the transition slab. On that basis, a modified geometry of the transition slabs is proposed for integral bridges.

Keywords: integral bridges, transition slabs, approach slabs, soil-structure interaction, road pavement serviceability

INTRODUCTION

During the service life of a concrete bridge, the bridge deck contracts due to creep and shrinkage as well as cyclic displacement due to thermal strain. To absorb the horizontal movement at the abutment the use of mechanical joints and bearings are commonly recommended as shown in figure 1 (a) to isolate the bridge deck from the embankment [1]. However, these mechanicals elements are often the weak points of the bridge, figure 2, and their use can lead to costly maintenance. Consequently, the use of integral bridges, figure 1 (b), without mechanical bearings and joints, are becoming more popular in practice for typical bridge lengths less than 60m [2, 3, 4]. The structure and the embankment are considered as a whole system in integral bridges in which the soil-structure interaction must be taken into account.

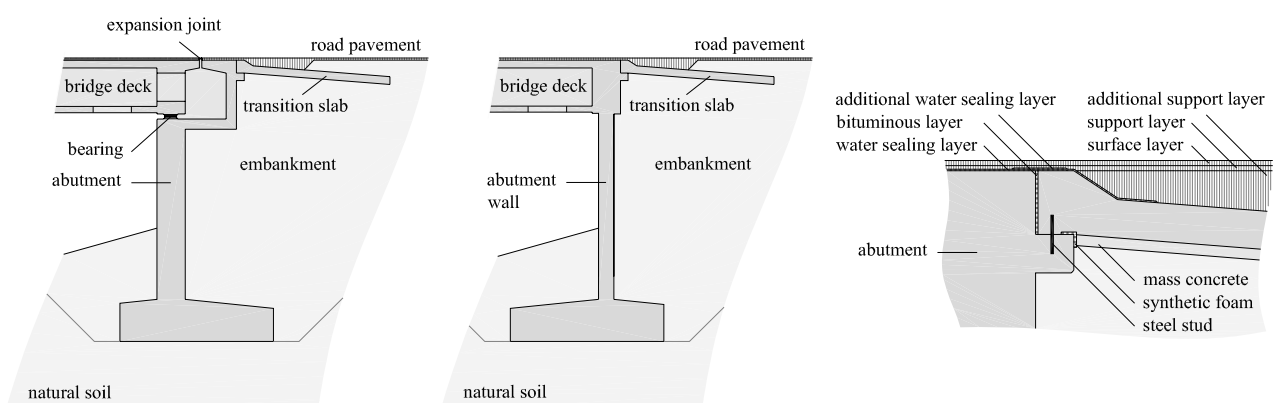

FIGURE 1. Elevation of the end of the bridge (a) standard bridge with mechanical joints and bearings (b) integral bridge without mechanical joint and bearings (c) detail of the connection between the abutment and the transition slab.

Transition slabs are located at the end of standard and integral bridges, figure 1 (a) and (b). They provide a smooth transition between the embankment and the bridge structure, even if a gap forms between the two due to settlement in the abutment or lack of embankment compaction. Figure 1 (c) shows current design recommendations

for abutment-transition slab connections by the Swiss Federal Road Office (FEDRO); the detail shown in figure 1 (c) allows the rotation of the transition slab around the steel stub and it is considered as a hinge.

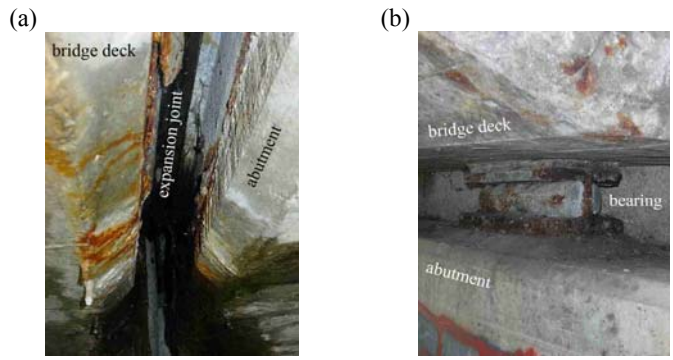

FIGURE 2. Damages caused by leaking of expansion joints (a) in the concrete joint region (b) at the bearing. [5]

PRESENT STUDY

As mentioned above, the use of mechanical joints and bearings make a physical separation between the abutment and the bridge structure; figure 3 (a). However, damages such as the ones shown in figure 2 have been observed with time even in joints and bearings which were correctly designed and detailed [5]. To avoid these damages, the end of the bridge can be designed monolithically i.e. as in an integral bridge. However, new types of problems related to the transition slab, which is connected longitudinally to the deck bridge, must be considered. Three main problems must be considered for the design of transition slabs as shown in figure 3 (b). Firstly a gap, marked as L_g in figure 3 (b), forms due to the displacement of the wall abutment (i.e. embankment active failure) which is connected to the bridge deck [6, 7]. The length of the transition slab L_{DT} must be design to be larger than length L_g. The second problem is the gap opening between the bridge deck and the transition slab caused by the rotation of the transition slab when subjected to horizontal bridge deck displacement u_{imp} [5]. A more suitable detail of the connection is achieved if the standard hinge is replaced by a concrete hinge as shown by Dreier and Muttoni in laboratory experiments [8]. Thirdly, the horizontal bridge deck displacement causes a road pavement settlement at the end of the transition slab. This paper focuses on the third problem and proposes a modified geometry of the transition slab to optimize its behaviour.

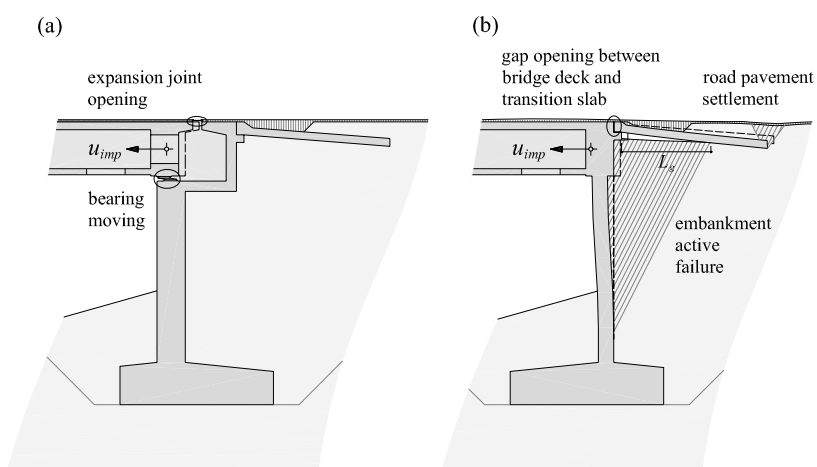

FIGURE 3. Problems caused by the longitudinal displacement of the bridge deck (a) standard bridge (b) integral bridge.

ROAD PAVEMENT SETTLEMENT

A numerical analysis was carried out by the author to evaluate the road pavement settlement caused by the longitudinal displacement of the bridge deck u_{imp}. The GefDyn finite element software [9] was used. The embankment was modelled using a Hujeux soil model [10, 11] whereas the concrete structure was modelled using an elastic model with a reduced Young modulus to take into account the cracking of the transition slab.

The main parameters of the embankment assumed in the model correspond to a typical granular soil of density weight of $\gamma = 19.4$ kN/m^3 and initial void ratio $e_0 = 0.32$. The bulk modulus was $K_{ref} = 47.1$ MPa and the shear modulus $G_{ref} = 21.7$ MPa at the mean reference effective pressure $p_{ref} = -0.1$ MPa and frictional angle $\rho = 36°$ [12].

The assumed transition slab geometry is shown in figure 4 (a). A parametric study was performed to study the variation of the transition slab length L_{DT} and slope α_{DT}. The 30 cm thick transition slab was kept constant. This thickness was given by constructive limitations.

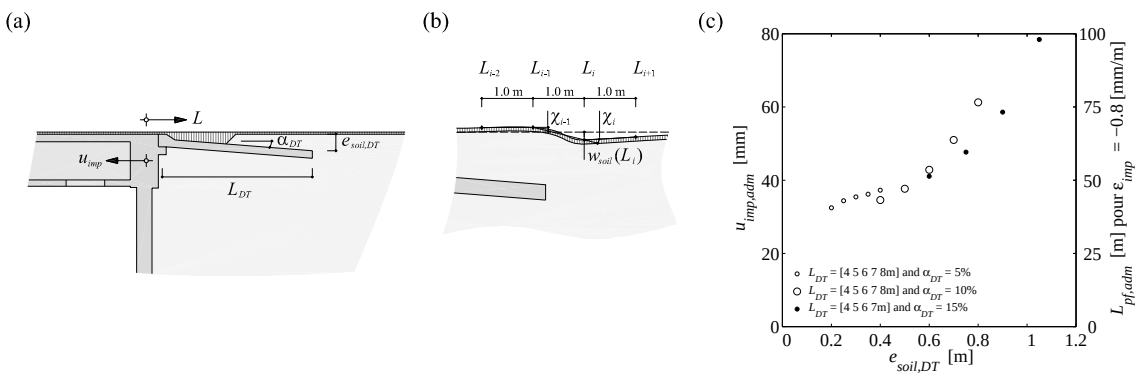

FIGURE 4. Numerical study (a) geometry of the transition slab (b) definition of the default (c) parametric study.

The serviceability limit state of the road pavement at the end of the transition slab is governed according to the Swiss Standard SN640520a [13] by the curvature of the pavement and not only by the vertical settlement. Indeed, for the road users, the discomfort depends on the height but also of the length of the settlement. The Swiss Standard SN640521c [14] defines the maximum value of the pavement curvature as $\chi_{adm} = 20‰$ for highway during service life. This curvature was determined as shown in figure 4 (b) [13].

The pavement curvature χ, wich depends on u_{imp}, was assessed from the deformations obtained in the numerical analysis. The maximum admissible horizontal displacement $u_{imp,adm}$ corresponds to χ_{adm}. Once $u_{imp,adm}$ is known, the maximum length of the bridge, i.e. the distance between the fix point and the abutment $L_{pf,adm}$, can be estimated using equation (1) to comply with serviceability restriction.

$$L_{pf,adm} = \left| u_{imp,adm} / \varepsilon_{imp} \right| \quad \text{where} \quad \varepsilon_{imp} = \varepsilon_{cr} + \varepsilon_{sh} + \varepsilon_{\Delta T,\min} \tag{1}$$

The fix point of a bridge subjected to expansion displacement is defined at the longitudinal location with zero displacements. If the geometry and the characteristic of the structure and embankment are perfectly symmetric, the fix point is located at the middle of the bridge length.

The imposed stain ε_{imp} consists of the strain components due to concrete creep ε_{cr}, shrinkage ε_{sh} and maximal negative temperature variations $\varepsilon_{\Delta T,min}$ of the bridge deck. In this work, the following values are used: $\varepsilon_{imp} \approx -0.8$ mm/m with $\varepsilon_{cr} \approx -0.3$ mm/m, $\varepsilon_{sh} \approx -0.3$ mm/m and $\varepsilon_{\Delta T,min} \approx -0.2$ mm/m.

Parametric study results

The parametric study presented in figure 4 (c), where the length L_{DT} and the slope a_{DT} of the transition slab was varied, shows clearly the main influence of the buried depth $e_{sol,DT}$ of the end of the transition slab in the embankment, see figure 4 (a). Parameter $e_{sol,DT}$ is given by equation (2).

$$e_{sol,DT} = L_{DT}\, \alpha_{DT} \tag{2}$$

Figure 4 (c) shows that the slope of $e_{sol,DT} - u_{imp,adm}$ is considerably larger for $e_{sol,DT} > 0.6$m.

The current Swiss recommendation which allows a maximum length of integral bridge of 60m [1] seems reasonable since the standard dimensions of transition slabs are $L_{DT} = 5 \div 6$m and $a_{DT} = 10\%$ which leads to $e_{sol,DT} = 0.5 \div 0.6$m i.e. $L_{pf,adm} \approx 40$m. However, this conclusion is correct only if the position of the fix point is roughly at the middle of the bridge length.

To increase the current Swiss limit on maximum length of integral bridges, a larger $e_{sol,DT}$ is needed. For example, to achieve a 100m integral bridge length with the fix point at the middle bridge length, a $e_{sol,DT} = 1$m is needed which results in a transition slab of 6.5m length with a slope of 15%. These dimensions are still reasonable for construction.

CONCLUSIONS

This paper presents the influence of the geometry of the transition slab of integral bridges on the serviceability limit state of the road pavement.

The main conclusions are:

1. The $e_{sol,DT}$, figure 4 (a), of the transition slab is the main parameter in the study of the serviceability limit states of the road pavement at the end of the transition slab for integral bridges.
2. Current Swiss limit for integral bridge length of 60m seems reasonable if the position of the fix point is roughly at the middle of the bridge length.
3. To increase the current Swiss limit on the integral bridge length, the length L_{DT} and the slope a_{DT} of the transition slab can be increased accordingly.

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